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Can the same visual modality express arousal or valence depending on the other modalities it is combined with?

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Abstract

The work described in this paper explores if the same visual modality (sharpness of curvature) can be used to express different dimensions of emotions (arousal and valence) depending on the modalities it is combined with. We propose two novel approaches to visually express emotions in affective agents. Both models employ a simplistic character consisting of an abstract body modelled as a closed sequence of concatenated curves. Emotions are represented in terms of arousal and valence dimensions. In the first model, the arousal value is expressed through the sharpness of the curves that comprise the character outline, while the valence value is expressed through the curvature of the character's mouth. In the second model, the arousal value is expressed through the character's movement, while the valence value is expressed through the sharpness of the curves that comprise the character outline. Thus, sharpness of curvature is used to express arousal in the first model and valence in the second one. The paper also describes a user experiment which investigated whether the arousal and valence expressed by our models are appropriately perceived by the users or not. The results support both models and suggest that sharpness of curvature could be used to express arousal or valence if consistently combined with other appropriate modalities.

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Keywords:
emotions, arousal, valence, digital character, curvature, movement.

1. Introduction

The digital management of emotions is a very active research topic since emotions were recognized as an essential factor of intelligence. This general topic includes recognizing, modelling and expressing emotions by digital means. Nowadays, the most usual way to express emotions in digital contexts is through the use of virtual characters. However, the use of human-like characters arises the problem of wrong expectations about the system's behaviour [1][2]. The human-like behaviour of the character in some aspects may lead the user to believe that the agent resembles human beings in other cognitive aspects as well. Thus, while the expression of emotions through realistic characters is useful in some contexts, there are other situations where virtual characters are neither necessary nor adequate. In this sense, we are researching more subtle,

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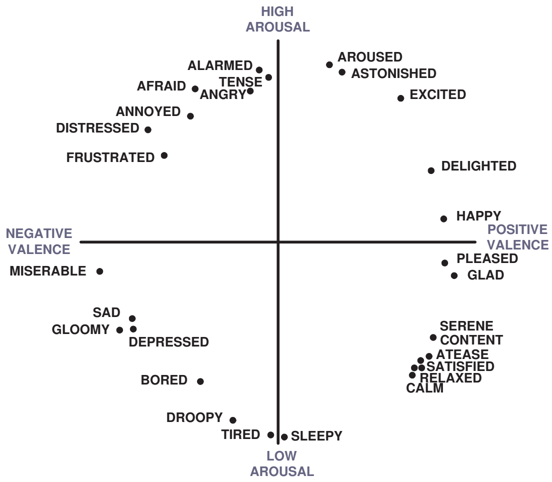


Fig. 1. Russell's circumplex model of affect

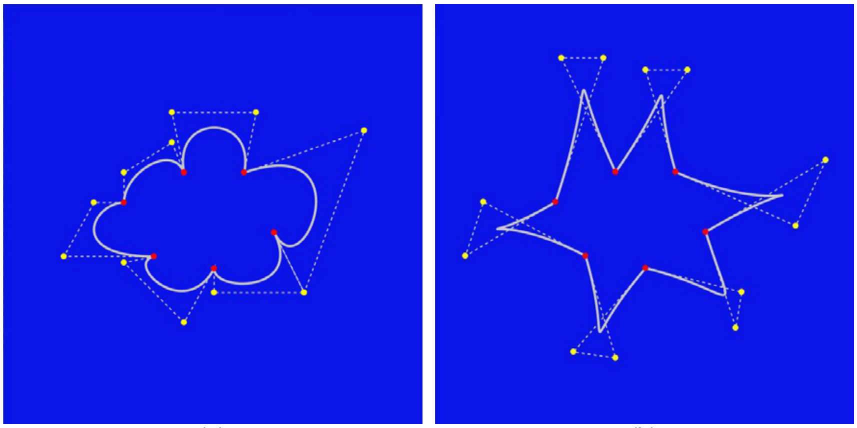
simpler and more iconic approaches for expressing emotions (see [3][4][5][6][7]). These approaches intend to minimize the user's expectations. The work presented in this paper follows this line of research.

There are two widely accepted coexisting approaches for modelling emotions: the categorical approach and the dimensional approach. Our model uses the dimensional approach which suggests the existence of major dimensions that are sufficient to describe and distinguish between different emotions. Russell's circumplex model [8] is among the most accepted dimensional models. Emotions are described in terms of two bipolar, continuous and orthogonal dimensions: the dimension of *valence* with the poles positive (or pleasure) and negative (or displeasure) and the dimension of *arousal* with the poles calm and excited. Several authors have described various different emotions using these dimensions by locating the emotion words in the bi-dimensional space. For instance, figure 1 shows some emotion words according to Russell's circumplex model of affect [8].

In this paper we explore if the same visual modality [1] can be used to express different dimensions of emotions depending on the modalities it is combined with. In particular, we explore if sharpness of curvature can be used to express arousal and valence. The election of sharpness deserves some explanation. The perception of curved versus angular lines and shapes has been studied in literature in terms of preference and several emotional aspects. For instance, Lundholm [9] found that angular lines are associated with feelings such as agitating, hard and furious. Curved lines were associated with feelings such as gentle, quiet and lazy. Similar results were found by Poffenberger and Barrows [10]. In an analogous study, Hevner [11] concluded that curves are found to be serene and graceful, while angles are robust and vigorous. Monö [12] showed that circles, spirals and shapes with smooth curves were more pleasant than shapes with hard angles. Silvia and Barona [13] found that people prefer round circles more than angular hexagons and curved polygons more than angular polygons. Leder and Carbon [14] found that curved designs are preferred to straight designs, and that curvature elicits increased positive emotions.

Literature review suggests that sharpness of curvature could affect both arousal and valence perception. In terms of valence, curved objects seem to be perceived as more positive than angular objects. In terms of arousal, curved objects seem to be perceived as less activated than angular objects. Thus, in principle, the sharpness of curvature could be potentially used for expressing both valence and arousal. We hypothesize that sharpness could be used for expressing valence (at the expense of its capability for expressing arousal) by combining it with other modalities that clearly express arousal (those other modalities could mask the arousal potentially denoted by sharpness). Similarly, we think that the capability of sharpness for

[1] Here we stand for the general semiotic meaning of "modality", that is, a particular way in which the information is to be encoded for presentation to humans



(a) (b)

Fig. 2. The character's body is generated as the interpolation of two extreme shapes: (a) a sequence of rounded Bèzier curves (corresponding to the lowest arousal in the first model and to the most positive valence in the second model) and (b) a sequence of sharp Bèzier curves (corresponding to the highest arousal in the first model and to the most negative valence in the second model)

expressing arousal could be emphasized by combining it with other modalities that clearly express valence. We explore those strategies via two different models. Both models use a simplistic character consisting of an abstract body (modelled as a closed sequence of concatenated curves). In the first model, the arousal value is expressed through the sharpness of the curves that comprise the character outline, while the valence value is expressed through the curvature of the character's mouth. In the second model, the arousal value is expressed through the character's movement, while the valence value is expressed through the sharpness of the curves that comprise the character outline.

The structure of the paper is as follows. First we detail the proposed models. Then we describe and discuss an experiment with users which investigated whether the arousal and valence expressed by our models are appropriately perceived by the users or not. Finally we show the conclusions and point out future work.

2. First model

The first model employs a pretty simplistic character consisting of a simple abstract body which only contains a plain mouth. The character's body is built by concatenating a series of curves. The emotion is represented in terms of arousal and valence dimensions and it is visually expressed through the outline and mouth of the character. The arousal value is expressed through the sharpness of the curves that comprise the character outline, while the valence value is expressed through the curvature of the character's mouth.

2.1. Arousal

The concrete character's body is constructed as a closed sequence of Bèzier curves. In particular, the body is generated as the interpolation of two extreme shapes: a closed sequence of 6 rounded Bèzier curves (see figure 2a) and a closed sequence of 6 very sharp Bèzier curves (see figure 2b). The first shape is used for expressing the lowest arousal. The second one is employed for the highest arousal. In figures 2a and 2b, the end points of the Bèzier curves are marked as red filled points, while the control points are marked as yellow filled points. Note that the end points of the rounded curves are located at the same coordinates that the corresponding end points of the sharp curves. Both shape models differ from each other only in the coordinates of the control points.

For values of arousal in between both extremes (the lowest and highest arousal), a new sequence of curves is generated as an interpolation of the two basic shapes (the rounded shape and the sharp shape). The end points of the new curves are identical to the end points of the original models. However, each

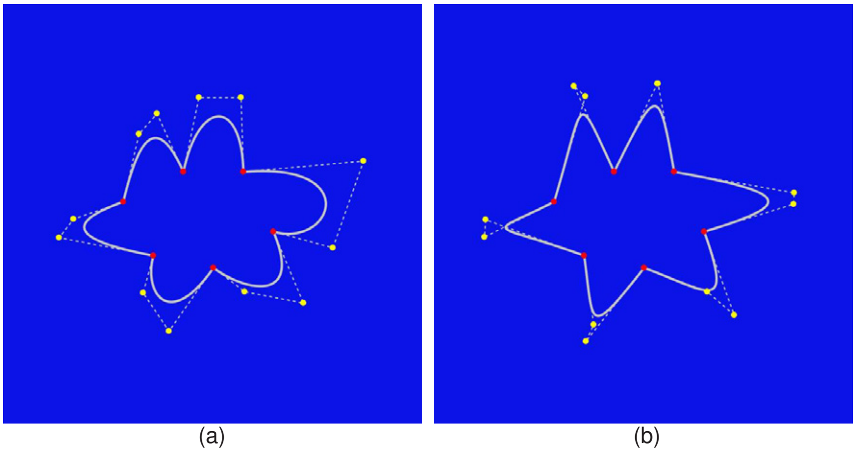


Fig. 3. Two closed sequences of curves generated for intermediate values, particularly (a) 3.3 and (b) 6.6 within the 0-10 range

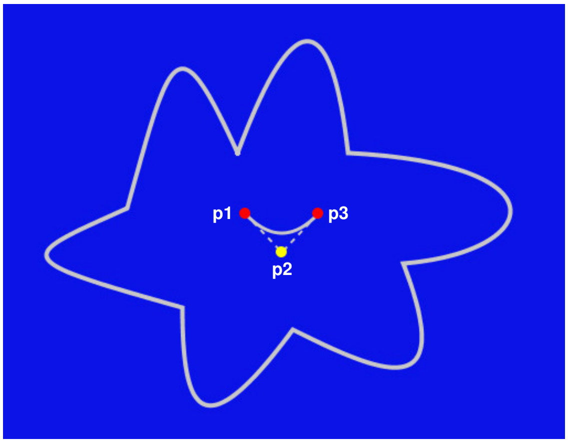


Fig. 4. The mouth (of the first model) is modelled as a quadratic parametric curve segment specified by three points

control point of the new curves is calculated as the linear interpolation of the corresponding control points of the extreme original shape models. As a result, the higher the arousal value is, the sharper the new curves are. On the contrary, the lower the arousal value is, the rounder the new curves are. Figure 3 shows two sequences of curves generated for intermediate arousal values; particularly 3.3 and 6.6, where the arousal value is within the 0-10 range (0 for the lowest arousal, 10 for the highest arousal).

2.2. Valence

Valence is expressed through the curvature of the character's mouth. More concretely, the mouth is modelled as a quadratic parametric curve segment specified by three points. These points are named $p1$, $p2$ and $p3$ in figure 4. Two of these points, the end points $p1$ and $p3$ (in red color), are fixed in both the horizontal and vertical axes. The location of the other point, the control point $p2$ (in yellow color), is fixed in the horizontal axis (it is located between the extreme points in the horizontal axis) but it is variable in the vertical axis. In particular, the vertical location of $p2$ depends on the valence value. The more negative the valence is, the higher the vertical location of $p2$ is. The more positive the valence, the lower the vertical location of $p2$ is. As a result, the valence value moving from negative to positive will move the mouth curvature from a downturn U to an upturn U.

In summary, valence influences the curvature of the character's mouth while arousal influences the sharpness of the character outline. Figure 5 illustrates those influences by showing four different combinations of

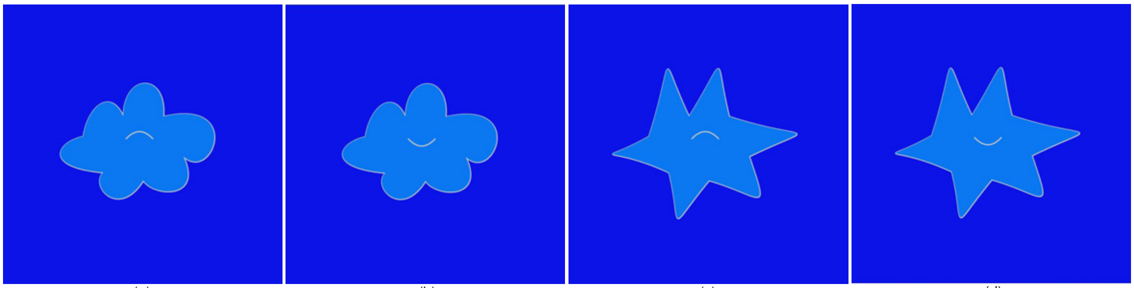


Fig. 5. Four different combinations of valence and arousal in the first model: (a) negative valence and low arousal, (b) positive valence and low arousal, (c) negative valence and high arousal and (d) positive valence and high arousal

valence and arousal. Note that the final character's body is filled with a plain light blue color.

3. Second model

The second model employs an even more simplistic character. It consists of the same abstract body as the first model, but without the mouth. The arousal value is expressed through the character's movement, while the valence value is expressed through the sharpness of the curves that comprise the character outline.

3.1. Arousal

The arousal value is expressed through the character's movement. In particular, the character's movement is controlled by a flocking algorithm which is influenced by the arousal value. We use a flocking algorithm because results from previous work [4] suggest that it is adequate. Our model uses a flock of n virtual beings to produce a fluid and natural motion. However, as we display only one character corresponding to one of these n virtual beings, the others $n-1$ virtual beings are only employed for calculation (they are not shown). The flocking behaviour in our system is based on boids [15], although the flocking behaviour itself is parameterized by the value of the arousal of the current emotional state. Therefore, in our model each virtual being moves along a vector, which is the resultant of three component vectors, one for each of the behavioural rules, which are:

- Cohesion - attempt to stay close to nearby flockmates.
- Alignment - attempt to match velocity with nearby flockmates.
- Separation - avoid collisions with nearby flockmates.

The calculation of the resultant vector, $Velocity$, for a virtual being A is as follows:

$$V_A = \underbrace{(Cf \cdot Cv)}_{Cohesion} + \underbrace{(Af \cdot Av)}_{Alignment} + \underbrace{(Sf \cdot Sv)}_{Separation} \tag{1}$$

$$Velocity_A = limit(V_A, (MVef \cdot MaxVelocity)) \tag{2}$$

where Cv, Av and Sv are the component vectors corresponding to the cohesion, alignment and separation rules respectively. Cf, Af and Sf are factors representing the importance of the component vectors Cv, Av and Sv respectively. These factors allow us to weight each component vector independently. $MaxVelocity$ is the maximum velocity allowed to the virtual being. In our current implementation Cf, Af and Sf and $MaxVelocity$ can be varied, in real time, from a user interface. $MVef$ is a factor whose value is calculated as a function of the current value of the virtual being's arousal. It allows an increase or decrease in the virtual being's $MaxVelocity$ depending on its arousal state. *limit* is a function whose value is equal to its first parameter if this is not greater than its second one, otherwise the function value is equal to its second parameter.

The resultant vector obtained by adding the three basic vectors is then scaled to not exceed the maximum speed. This maximum velocity is parameterised by the arousal. The greater the arousal, the greater the speed. As a result of this parameterisation of the flocking algorithm, the character seems to be more active as the aurousal value increases, and it seems to be more passive as the arousal value decreases.

3.2. Valence

As in the previous model, the character's body is constructed as the interpolation of the two extreme shapes shown in figure 2. In this model, the interpolation depends on the valence value (while in the previous model it depended on the arousal value). The rounded shape (figure 2a) is used for expressing the most positive valence. The sharp shape (figure 2b) is employed for the most negative valence. For values of valence in between both extremes, a new sequence of curves is generated as an interpolation of the two basic shapes. As a result, the more positive the valence value is, the rounder the new curves are. On the contrary, the more negative the valence value is, the sharper the new curves are. Figure 3 shows two sequences of curves generated for intermediate values; particularly 3.3 and 6.6, where the valence value is within the 0-10 range (0 for the most positive valence, 10 for the most negative valence).

4. User study

This section deploys an experiment which investigated whether the arousal and valence expressed by our models are appropriately perceived by the users or not.

4.1. Aims and hypotheses

The study has two aims for both models. The first aim is to investigate if both valence and arousal are correctly perceived when expressed by our models. Our hypotheses are:

H1: valence expressed by our models will be correctly perceived.

H2: arousal expressed by our models will be correctly perceived.

H3: both the perception of valence and the perception of arousal will be independent of each other.

The second aim of the study is to investigate if particular combinations of valence and arousal expressed by our models are correctly perceived as particular emotions. Our hypothesis is:

H4: particular combinations of arousal and valence expressed by our models will be correctly perceived as particular emotions.

4.2. Method

4.2.1. Participants

Thirty participants between the age of 24 and 47 (mean age = 35.59, SD = 5.36) took part in the study. Seventeen were men and thirty women. All of them had a degree. Participants were asked to rate their experience with computers. Self-reported experience with computers ranged from moderate to very experienced, with a majority rating their experience as reasonable or better. Participants were not paid for their participation in the study.

4.2.2. Equipment

For the experiment, we developed an application which implements the designed models. The application was developed in Java [16], employing Java2D [17] for graphics. The application provides an administrator interface which allows the administrator to vary, in real time, the values of both valence and arousal. In addition, the application can be controlled via an application programming interface (API). Thus, other applications can use it to display the emotional state of their systems.

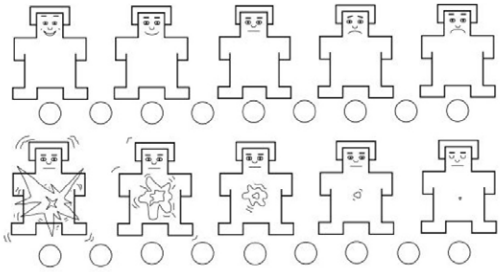


Fig. 6. Self-Assessment Manikin

4.2.3. Procedure

The experiment was conducted in a quiet room free of distraction. For each of both models, participants carried out the same series of tasks. The order of the models was randomised. For each model, participants, seated in front of the computer, were shown four windows, each containing a view of the character. Regarding the second model, as movement is involved, participants were shown a sequence of video that is 5 minutes long. The sequence comprised four windows, each containing a view of the character moving in the window. The order of the windows on the screen (for both models) was randomised. Each window corresponded to 1 of the 4 conditions listed below.

- A. Negative valence and a low level of arousal.
- B. Positive valence and a low level of arousal.
- C. Negative valence and a high level of arousal.
- D. Positive valence and a high level of arousal.

Note that conditions A, B, C, and D correspond respectively to the lower left, lower right, upper left, and upper right quadrants of the bi-dimensional valence-arousal space shown in figure 1.

Regarding the first aim of the study, participants were asked to rate each of the conditions according to valence and arousal scales. For this task we employed the paper and pencil version of the Self-Assessment Manikin (SAM), an affective rating system devised by Lang [18]. In this system, ratings of valence are indicated by graphic representations of facial expressions ranging from a broad smile (most positive) to a severe frown (most negative). For arousal, the manikin varies from a state of high to low agitation. In particular, we employed a 9 point Likert scale [19], as shown in figure 6. In the valence dimension, 1 represents the extreme of pleasantness and 9 the extreme of unpleasantness. For the arousal dimension, 1 represents a high activation and 9 represents a low activation.

Regarding the second aim, participants were presented with four tags corresponding to various emotional states. In particular they were presented with these tags:

- T1. Angry, enraged.
- T2. Excited, joyful.
- T3. Bored, sad.
- T4. Calm, satisfied.

Note that tags T1, T2, T3, and T4 correspond respectively to the upper left, upper right, lower left, and lower right quadrants of the bi-dimensional valence-arousal space shown in figure 1.

Participants were asked to assign each tag to the condition (concrete window) where they thought that emotion was being expressed.

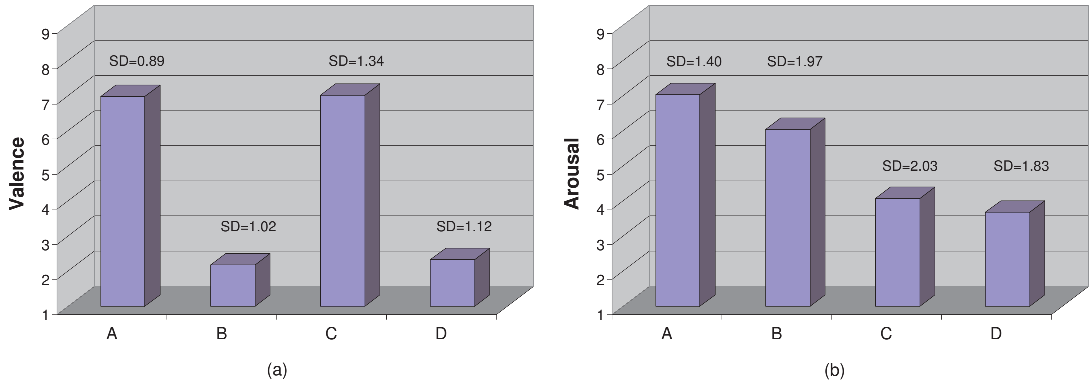


Fig. 7. Mean values and standard deviations for (a) valence and (b) arousal (in the first model)

Finally, participants were asked to rate each of the four tags of emotional states (T1, T2, T3 and T4) according to the valence and arousal scales. For this task we used the same version of the SAM employed in the previous one. Note that, in this task, the character was not taken into account. In fact, this task was included in the study as a control mechanism, in order to detect anomalies. For example, participants who rate sad as more positive than joyful would be discarded from the study.

4.3. Statistical analysis

Regarding the first aim of the study, for each studied aspect (valence and arousal) ordinal Likert scores were compared across conditions using Friedman's test for dependent samples [20]. Where significant differences where observed, a Wilcoxon signed rank test [21] was used to examine individual differences. All tests were 2-tailed. As to the second aim, the frequencies of tags for each condition were analyzed by using the chi-square goodness of fit test.

4.4. Results

4.4.1. First model

Regarding the first aim of the study, figure 7a summarizes the subjective ratings for valence. Each column displays the mean value of the corresponding condition and the standard deviation is shown above it. Note that in the valence dimension, 1 represents the extreme of pleasantness and 9 the extreme of unpleasantness.

Comparison shows that participants found that condition A had a more negative valence than conditions B ($z = 4.811$, $p < 0.001$) and D ($z = 4.808$, $p < 0.001$). Comparison also shows that participants found that condition C had a more negative valence than conditions B ($z = 4.741$, $p < 0.001$) and D ($z = 4.758$, $p < 0.001$).

On the other hand, figure 7b summarizes the subjective ratings for arousal. Each column displays the mean value of the corresponding condition and the standard deviation is shown above it. Note that for the arousal dimension, 1 represents a high activation and 9 represents a low activation.

Comparison shows that participants found that condition A had a lower level of arousal than conditions B ($z = 2.989$, $p < 0.01$), C ($z = 4.074$, $p < 0.001$) and D ($z = 4.383$, $p < 0.001$). Comparison also shows that participants found that condition B had a lower level of arousal than conditions C ($z = 2.857$, $p < 0.01$) and D ($z = 3.626$, $p < 0.001$).

The results regarding the second aim of the study are shown in figure 8. It displays the number of participants that assigned each tag (T1, T2, T3 and T4) to each condition (A, B, C and D). By using the chi-square goodness of fit test, a significant difference among the frequencies of tags was found in conditions A ($\chi^2(3, N = 30) = 90.0$, $p < 0.001$), B ($\chi^2(3, N = 30) = 75.067$, $p < 0.001$), C ($\chi^2(3, N = 30) = 90.0$, $p < 0.001$) and D ($\chi^2(3, N = 30) = 75.067$, $p < 0.001$).

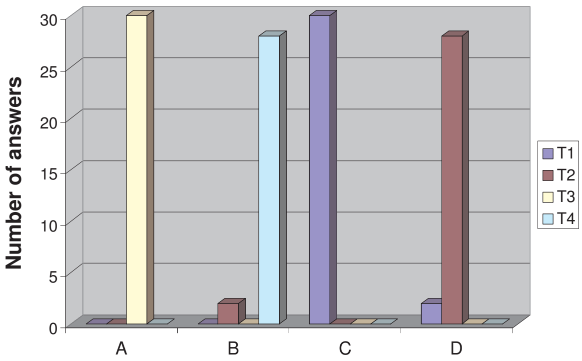


Fig. 8. Number of participants that assigned each tag (T1, T2, T3 and T4) to each condition (A, B, C and D) in the first model

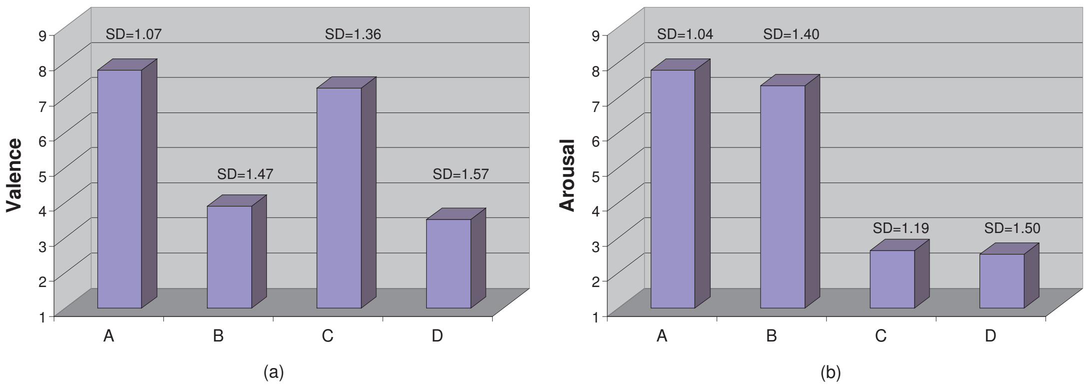


Fig. 9. Mean values and standard deviations for (a) valence and (b) arousal (in the second model)

4.4.2. Second model

Regarding the first aim of the study, figure 9a summarizes the subjective ratings for valence. Each column displays the mean value of the corresponding condition and the standard deviation is shown above it. Note that in the valence dimension, 1 represents the extreme of pleasantness and 9 the extreme of unpleasantness.

Comparison shows that participants found that condition A had a more negative valence than conditions B ($z = 4.639$, $p < 0.001$) and D ($z = 4.804$, $p < 0.001$). Comparison also shows that participants found that condition C had a more negative valence than conditions B ($z = 4.360$, $p < 0.001$) and D ($z = 4.640$, $p < 0.001$).

On the other hand, figure 9b summarizes the subjective ratings for arousal. Each column displays the mean value of the corresponding condition and the standard deviation is shown above it. Note that for the arousal dimension, 1 represents a high activation and 9 represents a low activation.

Comparison shows that participants found that condition A had a lower level of arousal than conditions C ($z = 4.806$, $p < 0.001$) and D ($z = 4.817$, $p < 0.001$). Comparison also shows that participants found that condition B had a lower level of arousal than conditions C ($z = 4.740$, $p < 0.001$) and D ($z = 4.742$, $p < 0.001$).

The results regarding the second aim of the study are shown in figure 10. It displays the number of participants that assigned each tag (T1, T2, T3 and T4) to each condition (A, B, C and D). By using the chi-square goodness of fit test, a significant difference among the frequencies of tags was found in conditions A ($\chi^2(3, N = 30) = 90.0$, $p < 0.001$), B ($\chi^2(3, N = 30) = 90.0$, $p < 0.001$), C ($\chi^2(3, N = 30) = 56.667$, $p < 0.001$) and D ($\chi^2(3, N = 30) = 56.667$, $p < 0.001$).

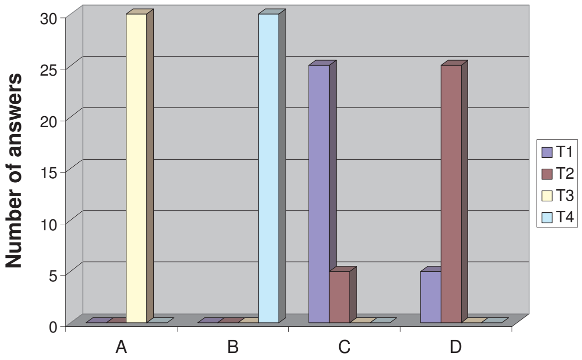


Fig. 10. Number of participants that assigned each tag (T1, T2, T3 and T4) to each condition (A, B, C and D) in the second model

4.5. Discussion

Regarding the first model, the results show that participants perceived a more positive valence in any of the conditions which had a positive valence than in the ones which had a negative valence (whatever its value for arousal was). In contrast, they did not perceive differences in terms of valence between the conditions which actually had the same value for valence. Thus, in principle these results seem to support the appropriateness of our approach to express valence through the mouth curvature.

The results also show that participants perceived a higher level of arousal in any of the conditions which had a high level of arousal than in the ones which had a low level of arousal (whatever its value for valence was). In contrast, they did not perceive differences, in terms of arousal, between the conditions which had a high level of arousal. However, interestingly, they did perceive differences in terms of arousal between the conditions which had a low level of arousal. More concretely, participants significantly perceived a lower level of arousal in condition A (negative valence and low arousal) than in condition B (positive valence and low arousal). Why does it happen? We found a plausible explanation while analyzing the results of the control questions. As indicated in section 4.2.3, participants were asked to rate each of the four tags of emotional states (T1, T2, T3 and T4) according to the valence and arousal scales. In this task, the character was not taken into account. It was included in the study as a control mechanism. We analyzed the results of the participants answers to these control questions and found that participants significantly rated a lower level of arousal for T3 (bored, sad) than for T4 (calm, satisfied). That is, emotions with negative valence and low arousal are considered as less aroused than emotions with positive valence and low arousal. These results are consistent with the significant difference found between conditions A and B. Thus, these results seem to support the appropriateness of our approach to express arousal through the contour sharpness.

As to the second model, the results show that participants perceived a more positive valence in any of the conditions which had a positive valence than in the ones which had a negative valence. In contrast, they did not perceive differences in terms of valence between the conditions which actually had the same value for valence. The results also show that participants perceived a higher level of arousal in any of the conditions which had a high level of arousal than in the ones which had a low level of arousal. In contrast, they did not perceive differences in terms of arousal between the conditions which had the same level of arousal. These results seem to support the appropriateness of our approach to express both valence through the contour sharpness and arousal through movement. Note that (as in both the first model and the control questions) participants perceived a lower level of arousal in condition A (negative valence and low arousal) than in condition B (positive valence and low arousal), although no significant difference was found in this case.

From the results, it seems that the same visual modality can be used to express different dimensions of emotions depending on the modalities it is combined with. In particular, sharpness of curvature can be used to express arousal (when mouth curvature is used to show arousal) or arousal (when movement is used to show valence). However, some considerations should be done in order to both limit the scope of these results and expose open problems beyond the presented work.

The models we have presented in this paper are intentionally simple. They were designed thinking of minimizing the number of dynamic visual modalities. In fact, each model has only two different modalities, one for valence and another one for arousal. The rest of the visual characteristics of each character (such as color, line thickness, size, etc.) remain unchanged. Thus, the found results are limited to this kind of simple model.

To illustrate the difficulties of expanding these ideas into a more complex model, assume a model where we use mouth curvature for expressing valence and movement for expressing arousal. Assume also that this hypothetical model includes sharpness of curvature as an additional dynamic characteristic. When the curvature was varied, would it be perceived as a change in valence? or as a change in arousal? or as both? or as something different? These questions show the difficulties of dealing with the expression of emotions through subtle features. Our hypothesis is that sharpness of curvature would be mainly perceived as valence if it were consistent with the mouth curvature (if they change in the same direction). It would be mainly perceived as arousal if it were consistent with the character movement. Otherwise, if sharpness did not maintain consistency with mouth curvature nor with movement, we think that it would not be perceived as valence nor arousal.

5. Conclusions

In this paper, we have explored if the same visual modality can be used to express different dimensions of emotions depending on the modalities it is combined with. In particular, we have explored if sharpness of curvature can be used to express arousal and valence. We defined two different models which use a simplistic character consisting of an abstract body. In the first model, the arousal value is expressed through the sharpness of the curves that comprise the character outline, while the valence value is expressed through the curvature of the character's mouth. In the second model, the arousal value is expressed through the character's movement, while the valence value is expressed through the sharpness of the curves that comprise the character outline. We have also described and discussed an experiment with users which investigated whether the arousal and valence expressed by our models are appropriately perceived by the users or not. The results support both models and suggest that sharpness of curvature could be used to express arousal or valence if consistently combined with other appropriate modalities.

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